United States
Department of
Agriculture

Forest Service

Pacific Northwest
Forest and Range
Experiment Station

Research Paper
PNW-309

September 1983

Wind Adjustment Factors for Predicting Fire Behavior in Three Fuel Types in Alaska

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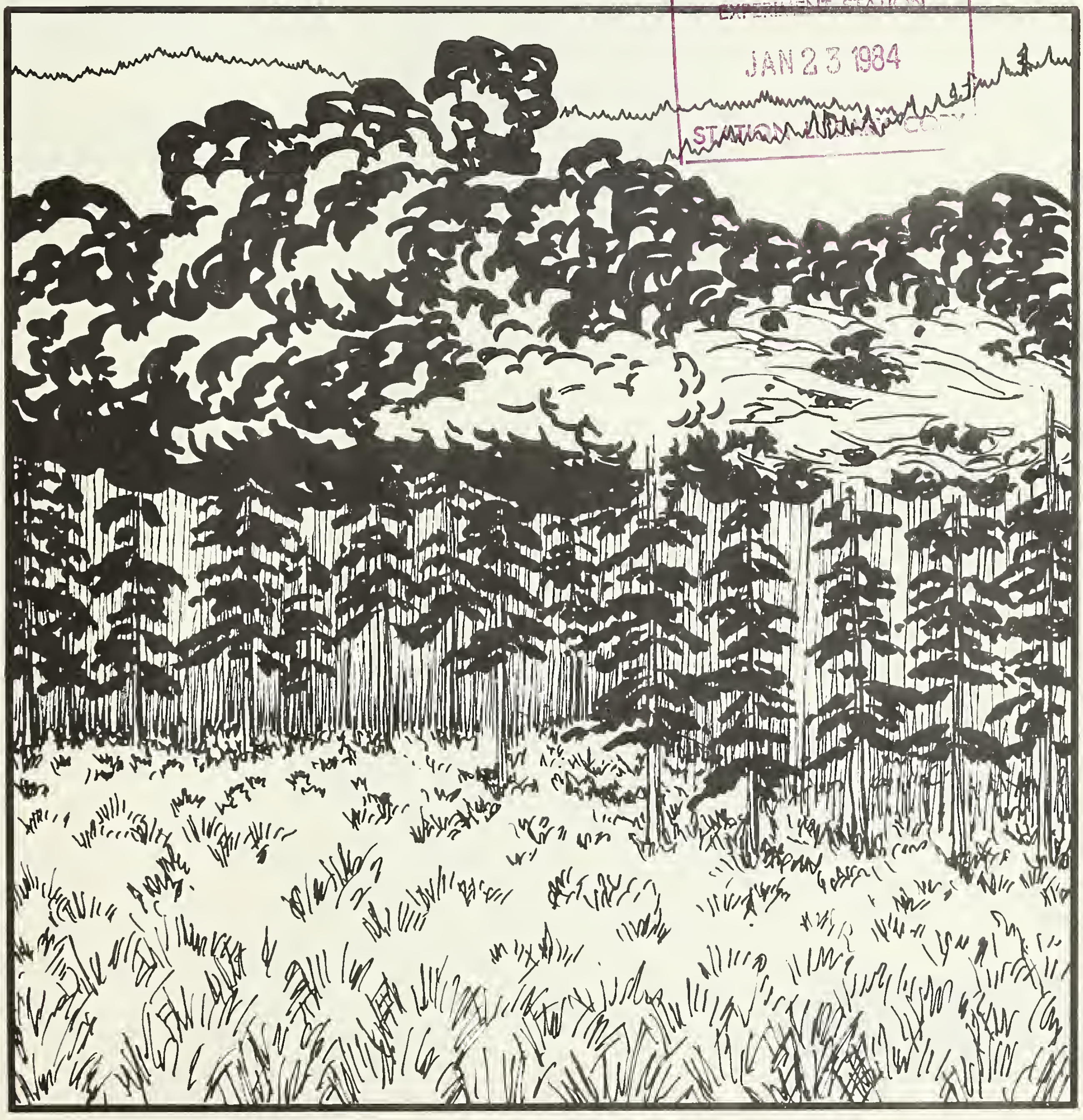

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Abstract

Norum, Rodney A. Wind adjustment factors for predicting fire behavior in three fuel types in Alaska. Res. Pap. PNW-309. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1983.** 5 p.

Factors for adjusting wind velocities from the 20-foot standard anemometer height down to an average wildfire midflame height (3.5 ft for the fuels studied) are given for exposed, partially sheltered, and sheltered fuels in Alaska. The values are suitable for predicting wildfire behavior.

Keywords: Fire behavior (forest), wind velocity, wind (-fire danger, fuels (forest fire), fuel management.

Introduction

The velocity of wind at the midflame height—3.5 ft (1.07 m) above the surface fuels in this case—is one of several variables required to estimate fire behavior by the system developed by Rothermel (1972, 1983). Albini (1976) and Burgan (1979) developed ways to use the system in the field. Most weather forecasts and recording stations give the windspeed at the standard 20-ft (6.1 m) height as described by Hardy and others (1955). An adjustment from the 20-ft height to the midflame height is needed because air flowing over the surface of the earth encounters friction that slows its movement, especially near the ground. Consequently, the windspeed at the 20-ft height is always greater than at the midflame height. The average midflame height varies from one wild-land fuel type to another and even within a given fuel type as environmental conditions change, but average values are used.

The fire behavior prediction system (Rothermel 1983) provides wind adjustment factors for fire in fuel types described as exposed, partially sheltered, or sheltered. The wind adjustment factor is the ratio of the windspeed at midflame height to the windspeed at 20-ft height, expressed as a decimal fraction. Wind adjustment factors for exposed fuels range from 0.36 to 0.55. The adjustment factor for partially sheltered fuels is 0.25, and factors for sheltered fuels range from 0.08 to 0.17.

Description of the Study

Alaska has unique fuel types that require special analysis if fire behavior predictions are to be accurate. Three common and important wild-land fuel types were chosen for a study of their physical and phenotypical responses to seasonal and short-term environmental influences. The very flammable black spruce/feathermoss (*Picea mariana* (Mill.) B.S.P./ *Hylocomium splendens-Pleurozium schreberi*) forests were given the most attention. The tussock tundra fuel type—consisting of *Eriophorum vaginatum* (L.) tussocks and various prostrate shrubs, herbs, and mosses—was selected because of its extensive distribution and recognized flammability. Because of their notable resistance to burning, the widely occurring deciduous tree forest types—paper birch (*Betula papyrifera* Marsh.) and aspen (*Populus tremuloides* Michx.)—were also selected for study.

Measuring instruments were placed at 19 sampling sites selected in 1980; 13 of these sites were located along 55 miles of the Melozitna River, which forms a confluence with the Yukon River at Ruby, Alaska. These 13 sites are reported on here; 5 are in black spruce stands, 4 in tussock tundra, and 4 in hardwoods.

While the standard National Fire-Danger Rating System weather data and live and dead fuel samples were being collected, the standard 20-ft windspeed and the midflame windspeed were recorded at each site as close to 2:00 p.m. (Alaska daylight time) as possible (fig. 1). A typical installation is shown in figure 2.

Because of the varying height of the upper level of the surface fuel, the precision of the vertical placement of the midflame anemometer was ± 0.5 ft. Interviews with experienced firefighters yielded the consensus that flame lengths of surface fires in these fuel types range from 2 to 5 ft under commonly encountered wildfire conditions. The cost of instrumentation dictated that a common value for the height of the midflame windspeed measurement be used; 3.5 ft was chosen.

Figure 1.—Windspeed at midflame height (3.5-ft) and 20-ft windspeed were measured simultaneously.

Figure 2.—Weather station installation on tussock tundra.

Instrumentation and Data Collection

Anemometers were permanently installed 20 ft above the vegetation (fig. 2) on each site, and a portable anemometer for measuring midflame windspeed was mounted on a staff (fig. 1). All anemometers were maintained to start at a windspeed of 1 mile per hour (mi/h) or less. Standard electronic contacting anemometers were used, with their 1/60-mile contacts connected to accumulating counters. The anemometer for measuring windspeed at midflame height was located away from the weather shelter or other artificial obstruction and at a spot most typical of the conditions on each site. The counters for both anemometers were started simultaneously, to the nearest second. The time of measurement (also to the nearest second) and the number of contacts generated by each anemometer were recorded at the end of each sampling period; 10 minutes was the shortest recording period allowed. The windspeed was then calculated by the equation:

$$\text{Windspeed (mi/h)} = \frac{\text{number of contacts}}{\text{number of minutes}}.$$

One pair of values was collected at each site daily. Of the windspeed measurements taken, 71 pairs were on black spruce sites; 34 on hardwood sites; and 68 on tundra sites.

Results

Paired values of 20-ft and midflame windspeeds from the black spruce, tussock tundra, and deciduous tree sites were recorded individually. The goal was to find the ratio of the midflame windspeed to the 20-ft windspeed, so a simple average ratio of these daily measurements was calculated (tables 1, 2, and 3). Simple linear regression equations were then calculated for the paired values from each site. The results are listed in tables 1, 2 and 3 under "Regression equation." The coefficient of determination (r^2) and the standard error of the regression ($S_{y \cdot x}$) are also listed. Because the density of a stand of trees strongly influences the wind reduction factors, the percentage of canopy cover of the forested sites is also listed in tables 1 and 3.

The regression equations for each fuel type were tested for differences at the zero intercept and for slope among sites. Where there was no significant difference (90-percent confidence level), all pairs of windspeed values for that fuel type were pooled, and an overall simple linear regression equation was calculated.

Table 1—Wind adjustment values and associated data for black spruce stands in Alaska

(x = 20-ft windspeed—miles per hour; y = midflame windspeed—miles per hour)

Site number	Simple average ratio	Regression equation	r^2	$S_{y \cdot x}$	Canopy cover
					Percent
1	0.13	$y = 0.13 + 0.11x$	0.81	0.25	80
2	0.24	$y = 0.25 + 0.21x$	0.91	0.54	45
3	0.22	$y = 0.07 + 0.20x$	0.81	0.51	40
4	0.30	$y = 0.38 + 0.46x$	0.92	0.32	45
5	0.15	$y = 0 + 0.17x$	0.84	0.37	40
2, 3, 5 (pooled)	0.21	$y = 0.10 + 0.21x$	0.85	0.53	—

Table 2—Wind adjustment values and associated data for tussock tundra sites in Alaska

(x = 20-ft windspeed—miles per hour; y = midflame windspeed—miles per hour)

Site number	Simple average ratio	Regression equation	r^2	$S_{y \cdot x}$
1	0.69	$y = -0.10 + 0.70x$	0.98	0.83
2	0.75	$y = -0.04 + 0.76x$	0.99	0.45
3	0.78	$y = -0.23 + 0.81x$	0.99	0.54
4	0.72	$y = -0.72 + 0.83x$	0.99	0.67
1, 2, 3, 4 (pooled)	0.75	$y = -0.12 + 0.75x$	0.99	0.68

Table 3—Wind adjustment values and associated data for hardwood sites in Alaska

(x = 20-ft windspeed—miles per hour; y = midflame windspeed—miles per hour)

Site number	Simple average ratio	Regression equation	r^2	$S_{y \cdot x}$	Canopy cover
					Percent
1	0.31	$y = -0.02 + 0.36x$	0.92	0.74	85
2	0.27	$y = -0.06 + 0.29x$	0.90	0.52	75
3	0.43	$y = -0.31 + 0.53x$	0.95	0.71	25
4	0.31	$y = 0.01 + 0.31x$	0.91	0.38	75
1, 2, 4 (pooled)	0.31	$y = 0.02 + 0.31x$	0.85	0.50	—

Discussion of Results

Within the black spruce fuel type, the wind adjustment factors for sites 1 and 4 were significantly different from the others, probably because of differences in stand structure; therefore, sites 2, 3, and 5 were pooled to give the regression equation listed under "pooled" values in table 1.

No statistically significant differences were found among any of the tussock tundra sites, so the values for all sites were pooled. The resulting regression equation is reported under "pooled" values in table 2, along with its associated statistics.

One hardwood site was significantly different from the other three, probably because of its exposed location on a ridgetop and its open stand structure. Site 3 was segregated, and the remaining values were pooled to get the regression equation at the bottom of table 3.

Notably, the adjustment factors for the tundra sites exceed any wind adjustment factors recommended for use by fire behavior officers (Rothermel 1983). The tussock tundra is an exceptionally smooth, homogeneous surface (fig. 2). Consequently, the midflame windspeed is fully three-fourths that of the 20-ft windspeed.

The structure of black spruce forests in Alaska is quite variable, as the data in table 1 indicate. The simple average rates for black spruce site 1 is 0.13, and the value for site 4 is 0.30. Site 1 is a dense, closed stand with a canopy cover of 80 percent. Site 4 is on the upper one-third of a very exposed ridge where moving air can penetrate the stand. It has a canopy cover of only 45 percent. The other three stands are apparently more typical of interior Alaska and fit the category of partially sheltered fuels as described by Rothermel (1983). A wind adjustment factor of 0.21 seems appropriate because the slope of the regression line is also close to that figure.

The wind adjustment factors for hardwood sites are surprisingly high, indicating that these open stands permit air to flow freely through them. The slope of the regression line for the three pooled sites is 0.31, putting them in the range of fuels described as exposed by Rothermel (1983). This is probably due to the absence of tree branches near the ground.

The regression equations for the pooled values from each fuel type probably represent typical situations in interior Alaska, although more measurements would be useful. Further, in most cases, the zero intercept is so small that the slope of the regression line can be used as an adjustment factor with little error, simplifying the procedure for field use. Table 4 lists the values to be used for fuels in Alaska. To obtain an estimate of the midflame windspeed on tussock tundra, multiply the 20-ft windspeed (forecasted) by 0.75. Do likewise in typical black spruce, using 0.21; and in hardwoods, 0.31. If the black spruce forest is very dense, with canopy cover near 80 percent, the values published by Rothermel (1983) for fully sheltered fuels should be followed. The equation for black spruce site 1 suggests a value of 0.11. In very open black spruce stands on exposed ridges, a value as high as 0.46 may be suitable. Open hardwood stands on exposed ridges may require the use of a wind reduction factor as high as 0.53.

Table 4—Recommended wind adjustment factors for 3 types of fuel in Alaska

Fuel	Adjustment factor [1]
Black spruce:	
Dense, mature stands on flat or rolling terrain	0.11
Open stands or dense stands on the upper 1/3 of exposed ridges	.21
Very open stands on exposed ridges	.46
Tussock tundra	.75
Hardwoods:	
Birch or aspen stands on flat or rolling terrain, with leaves on trees	.31
Birch or aspen stands, widely spaced or on the upper 1/3 of exposed ridges	.53

[1] These values should be used only for stands in the interior of Alaska.

Conclusions

Some important conclusions may be drawn from these findings. Anyone forecasting wildfire behavior in Alaska should note the large difference in wind adjustment factors between these three commonly encountered fuel types. The value for tussock tundra should be given special attention because it is substantially higher than any wind adjustment factor previously suggested for fire behavior predictions. If a fire moves from a black spruce forest onto a tussock tundra, a threefold or greater increase in midflame windspeed can occur without any change in the 20-ft windspeed. Consequently, a very rapid increase in rate of spread should be anticipated. The same possibility should be considered when prescribed fires that include both the black spruce and tussock tundra fuel types are planned. The prescription limits should consider the much higher effective windspeed on tussock tundra portions of a proposed prescribed fire area. Although the surface fuels in hardwoods in Alaska are meager and fires in these forests are notably mild, the relatively high midflame windspeeds can carry fire when conditions are right.

The possible transition from one wind adjustment factor to another during a fire within a fuel like the black spruce type must also be considered. A fire beginning in a dense black spruce stand may require a wind adjustment factor as low as 0.11 (see table 1). As the fire grows to several thousand acres, however, the wind will be blowing across the barren, burned area which will then have a much higher wind adjustment factor. Therefore, wind adjustment factors in dense black spruce stands may be much lower for small fires than for very large fires, and they may change as the fire grows.

Summary

Simultaneous measurements of the speed of the wind at the 20-ft standard height and at 3.5 ft above the surface fuels (midflame height) lead to the wind adjustment factors given in table 4.

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